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## Design Challenges of a Maritime Multipurpose Unmanned Vehicle

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# DESIGN CHALLENGES OF A MARITIME MULTIPURPOSE UNMANNED VEHICLE

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**Abstract.** Military Navies have several missions in which due to their complex, dangerous, or disaster scenarios, unmanned vehicles are suitable to perform the necessary tasks. Besides other issues it is a current subject of research the trade-off between using many mission oriented unmanned vehicles or the use of less number of more robust and versatile multimission vehicles. Challenged by the technological advances achieved in mobile robotics and unmanned vehicles, and the need to develop in house know-how, this project aimed to put into practice the development of a concept design of a multimission unmanned surface vehicle, that can operate individually or cooperate with other systems whose development will be done in parallel on other projects.

This unmanned vehicle, designated Unmanned Surface Vehicle for the Portuguese Navy - USV – PoN is part of project based oriented learning strategy in development in the Portuguese Naval Academy. It poses particular challenges related to the broad spectrum of the concept of operations, such as mine warfare operations, port surveillance and protection operations, search and rescue operations, hydrographic data collection operations. All of these operations demand different and challenging missions and tasks, to which the concept design of the USV-PoN will answer in terms of feasibility studies and possible configurations.

The purpose of this work is to address the challenges that the concept of operations and corresponding technical specifications put into the design of the USV-PoN and show how to overcome them making the study and analysis necessary for the production of a prototype based on the concept design.

Out of the scope of this work were aspects related to sensor development and integration as well as the command and control of the vehicle.

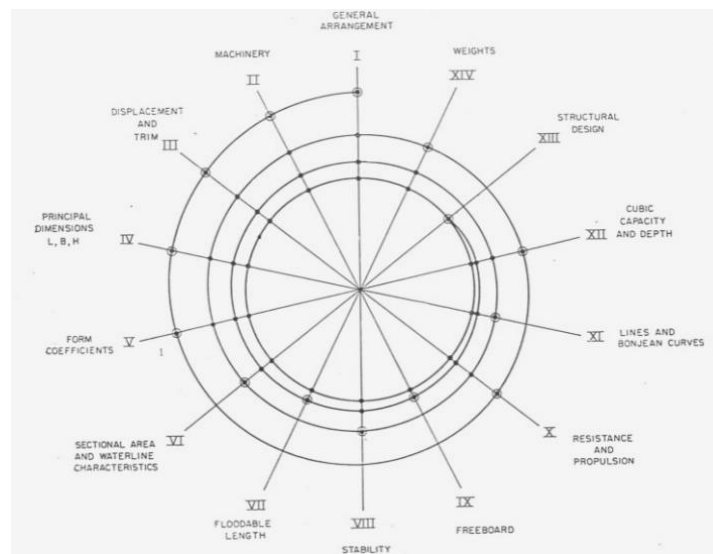
## 1. Introduction

Due to the different missions and tasks undertaken by the military Navies, in complex, dangerous and disaster scenarios, it is necessary to reduce the risk to its military and increase responsiveness to different threats, in any type of scenario.

As part of a line of research with interest to the CINAV (Naval Research Center) and the strategic plan of the Portuguese Navy, it was started in 2017 the development of the conceptual design of an Unmanned Surface Vehicle (USV).

This vehicle is possibly intended to be an ocean-going platform. As such its design as any novel design is a complex and challenging activity. It demands a large spectrum of knowledge on diverse scientific areas combined with an iteration process that takes the designer through the same design detail several times, as needed to improve the object of design up to the point where the constraints of adequacy, feasibility and acceptability are met. Other way to put it is to apply an iteration process that improves slightly the design up to obtain an optimum, as Evans H. explains in his well-known Design Spiral [1].





**Figure 1** - Design Spiral from Harvey Evans [1].

As far as concerns to the acquisition process of naval means, it was adopted as a reference the publication NATO AAP-20: PAPS (Handbook on the Phase Armaments Programming System) [2], now known as NATO AAP-20: NATO Programme Management Framework (NATO Life Cycle Model) [3]. This publication is a manual which describes a phased programming system for the design and procurement of military assets. For the design of this platform the relevant phases of the NATO framework are the phases 3 to 6, which correspond to the tasks and deliverables of ship design [4].

Phase 3, the *Pre-feasibility Studies*, is when the design of a naval platform begins and a preliminary evaluation of technical concepts which can meet the objectives defined in phases 1 and 2, is performed. This phase ends with the preparation of the *Consolidated Operational Objectives*.

Phase 4, *Feasibility Studies*, involves the more detailed elaboration and evaluation of the most promising technical concepts that meet the *Consolidated Operational Objectives*, in order to identify the most advantageous alternative that is feasible from the technical point of view and from the point of view of the cost and duration constraints of the project. This phase concludes with the drafting of the *Operational Requirements* document, which reflects the selection of the most advantageous workable alternative.

It is only in phase 5, *Project Definition*, that the "design" of a ship takes shape and size. It is a phase whose objectives are the detailed specification of the ship and the development of the initial specifications of the sub-systems. This phase concludes with the elaboration of the *Project Development Objectives*.

The ship design is completed in phase 6, *Project Development*. It is at this stage that various engineering, detailed ship design and prototype manufacturing processes are developed, which will validate the project in order to allow the production contract to be advanced.

This work is focused on the practical application of the NATO framework, with the necessary adaptations to the nature and dimension of the asset, within which a first iteration of the design spiral is to be detailed.

For pursuing the previously described acquisition and design processes, it is necessary to reflect, analyze and list what are the tasks and activities to develop for the present platform.

Then it is necessary to work on what materials and equipment are required to perform the tasks.

Being known the first estimation of weight and volume of all equipment, it is possible to start the initial sizing studies, through empirical-analytical methods adapted to platforms with small dimensions.

The initial sizing gives first estimates of the main dimensions of the platform and the weight and volume of the structure of the platform, as well as the height of the centre of gravity.

Once the initial dimensions are known, 3D modelling of the platform can be carried out using a CAD/CAE software, such as *SolidWorks*<sup>®</sup>.

We conclude the study for this work, modelling the platform in *AutoHydro*<sup>®</sup> software where it is possible to obtain the stability curves, which allows to revise previous decisions and redesign the platform.

## 2. Concept of Operations

In the initial phase of the design, what is inserted in phases *Pre-feasibility* and *Feasibility Studies*, it is necessary to think "What is the platform for?", "What will the platform do?". It is at this stage that the Operational Requirements are defined, where the missions and tasks to be carried out by the platform are chosen.

### 2.1. Operational Requirements

Before defining any mission to be developed by the platform, it was necessary to define the area of operations. Then it was defined a broad range of operations, e.g. search and rescue, hydrographic survey, etc.

Due to the wide variety of operations required at this phase, and the predictable unfeasibility and acceptability of this spectrum of operations in a single platform as well as existence of overlap between them, it was necessary for a first iteration of the design to prioritize the most important and necessary operations. After some reflection and rational analysis based on the main needs of the organization and the maximization of the number of missions with common equipment it was concluded that a single platform will have to be able to carry out the following operations:

- maritime search and rescue operations;
- force protection operations and port protection;
- environmental data collection operations;
- hydrographic surveys operations.

Once defined the operations to be developed by the platform, it will be necessary to define the tasks to be performed in each mission/operation, e.g.:

- maritime search and rescue operations:
  - Detection of contacts (people and boats);
  - Automatic contact tracking;
  - Transport and release of rescue equipment.
- environmental data collection operations:
  - Water and air temperature;
  - Absolute and relative humidity;
  - Direction and intensity of the wind;
  - Atmospheric pressure.

### 2.2. Technical Requirements

In parallel (involving interaction between end-user and designer) or after defining the operational requirements, it is also imperative to define the technical requirements or technical specifications. These define the limitations/obligations of the technical characteristics of the platform, such as autonomy, maximum weight, maximum speed, etc that can fulfil the operational requirements within existing constraints. Some constraints are:

- the platform should be prepared to be stowed either on board of the Navy ships or in a trailer to be defined in its own specs. Therefore, it was necessary to verify the limiting working load that the cranes of the different ships, as well as the berthing. Thus limiting the vehicle maximum displacement and dimensions.

With the demanding maritime agitation and high intensity of wind present on the Portuguese coast, it is desirable that the vehicle is able to operate in rough sea conditions, defined as sea state 5 on Douglas scale - up to 4 meters significant wave height -, and wind force 6 on the Beaufort scale.

For the hull to withstand these conditions, it is necessary to be constructed with materials in agreement with. It is also necessary that the materials used have high resistance to corrosion.

Due to its maritime search and rescue mission, this vehicle should be designed to carry a liferaft for four shipwrecked. In addition to this requirement, the platform should provide for 2 shipwrecked to easily rise on board and to remain on board for short periods of time, namely from the place of the shipwreck to the mother ship, or to the nearest port.

In order to navigate areas common to other vessels, the platform must have the lighting provided in COLREGS (International Regulations for Preventing Collisions at Sea) for boats of its characteristics, or approximate, and thus be able to navigate safely.

Among many other technical requirements, it should be noted that the platform should have self-righting characteristics.

### 3. Preliminary Studies

The preliminary studies are considered in the *Project Definition* phase. Here we will present some studies that have been carried out to determine which type of hull is most suitable to be used on this vehicle and also what equipment will be needed to equip the platform in order to be able to perform the operations defined above.

#### 3.1. Hull Type

An multicriteria initial evaluation was developed in order to obtain the types of hulls most used in USV's, from which the following list was obtained:

- Planning;
- Semi-planning;
- Hydrofoil;
- Multi-hull;
- SWATH.

Some general characteristics were defined that may characterize the different types of hull, and they are:

- survivability;
- seakeeping;
- hull resistance to advance;
- deck floor area;
- flexibility in load arrangement;
- ease of design/production;
- launch and recovery;
- transportability.

Once the different hull types were chosen and the general characteristics defined, a matrix was constructed which is represented in figure 2, where a weight of importance is assigned to the general characteristics, where the value 1 represents the least important characteristic and 8 the most important characteristic. For the different types of hull, a value of 1 to 5 has been assigned depending on whether the type of hull is “well”, to “not appropriate” for a given characteristic, where the value 1 means that it is not appropriate and 5 well appropriate.

Importance	General Features	Hull Types				
		Planing	Semi-Planing	Hydrofoiled	Multihull	SWATH
1	Resistance to sinking	3	3	3	5	5
2	Seakeeping	2	3	1	4	5
3	Resistance to advance	3	2	5	4	1
4	Deck floor area	2	3	1	4	5
5	Flexibility in load arrangement	4	5	4	3	3
6	Ease of design/production	4	5	1	3	2
7	Launch and Recovery	5	4	1	2	2
8	Transportability	5	5	1	2	1
		109	111	42	82	67
36		3.0	3.1	1.2	2.3	1.9

**Figure 2** - Decision matrix for hull type selection

The best type of hull will be the one that will present the highest value when applied to equation (1) to the different types of hull.

$$\frac{\sum_{i=1}^8 (importance_i \times Hull\ Type_i)}{\sum_{i=1}^8 Importance_i} \quad (1)$$

In this way it is concluded that the best type of hull to apply on the platform could be a semi-planning hull, but a planning hull is also an adequate choice. A planning hull was chosen to develop due to easiness of modelling and time constraints.

### 3.2. Equipment

To know the payload, it is necessary to choose which equipment to put on the platform. The equipment is chosen so that the platform can carry out the different operations defined previously.

As an example, for search and rescue operations at sea, the platform should be equipped with:

- Sidescan sonar;
- Sonar;
- IR Camera;
- Life raft.

For the other missions the same or other equipment is needed.

In addition, the vehicle will require equipment that allows it navigate safely, such as:

- GPS;
- GNSS;
- RADAR;
- Batteries;
- Propulsion system.

In this work the technical questions related with autonomous operation were not addressed yet.

With the equipment defined, a search was made in the market with the purpose of obtaining the weight and volume of each equipment, and adding up all the weights and volumes of the equipment, up to obtain the payload.

**Table 1** - Payload example

	Weight [kg]	Volume [m <sup>3</sup> ]
RADAR	5,60	0,193
GPS	0,24	0,001
GNSS	0,50	0,005
BATTERIES	21,50	0,011
SIDECAN SONAR	1,10	0,001
SONAR	27,60	0,035
IR CAMERA	27,20	0,369
LIFE RAFT	28,00	0,091

The first estimate for total payload weight was about 230 kg and 1 m<sup>3</sup> of volume. A margin of 5% was taken for cable weight, platform fastening and other unknown payload variables.

#### 4. Sizing and Geometric Modelling

In the initial sizing of the USV-PoN it is necessary to identify the main characteristics of the hull such as length (L), beam (B), draft (T) and depth (D). This process is still inserted in the *Project Definition* phase.

To calculate these characteristics, one made use of analytic-empirical methods adapted for small-scale platforms.

To start the calculations, a list of Unmanned Surface Vehicles (USV's) with characteristics similar to those intended for the study of this platform were chosen, in order to obtain an average of the characteristic form coefficients for this type of vehicle. The list of vehicles studied and their main characteristics are shown in table 2.

**Table 2** - Database of USV's characteristics.

	C-Sweep	C-Worker 5	C-Worker 6	C-Worker 7	C-Worker 8	C-Target 3	C-Target 6	C-Target 9	C-Target 13
Length [m] L	10,8	5,5	5,8	7,2	7,7	3,5	6,5	9,6	12,9
Beam [m] B	3,5	1,7	2,2	2,3	2,1	1,4	2,1	2,4	2,7
Depth [m] D	2,9	1,8	2,2	2,1	2,1	1,3	1,0	1,4	2,0
Draft [m] T	0,7	0,9	0,9	0,9	1,0	0,6	0,3	0,4	0,5
Displacement [ton] Δ	9,0	1,9	13,5	5,3	4,8	0,3	1,2	2,8	4,2
Volume of Displacement [m <sup>3</sup> ] ∇	8,8	1,9	13,2	5,2	4,7	0,3	1,2	2,7	4,1

With the main characteristics it is possible to calculate the form coefficients of each hull in order to establish an average of these form coefficients, which in turn allows for the calculation of the initial dimensions of the USV-PoN [5]. The form coefficients considered were:

- Circular M:

$$M = \frac{L}{\nabla^{1/3}} \quad (2)$$

- The Beam/Draft ratio ( $K_B$ ):

$$K_B = \frac{B}{T} \quad (3)$$

- Block coefficient ( $C_B$ ):

$$C_B = \frac{\nabla}{L \times B \times T} \quad (4)$$

It was also calculated the following ratios:

$$\frac{L}{B} \quad (5)$$

$$\frac{T}{D} \quad (6)$$

The form coefficients are shown in table 3:

**Table 3** - Hull Coefficients

	C-Sweep	C-Worker 5	C-Worker 6	C-Worker 7	C-Worker 8	C-Target 3	C-Target 6	C-Target 9	C-Target 13	Mean
M	5,2	4,5	2,5	4,2	4,6	5,1	6,2	6,9	8,1	5,24
$K_B$	5,0	1,9	2,4	2,6	2,2	2,3	7,0	6,0	5,4	3,86
$C_B$	0,3	0,2	1,1	0,3	0,3	0,1	0,3	0,3	0,2	0,36
L/B	3,09	3,24	2,64	3,13	3,60	2,50	3,10	4,00	4,78	3,34
T/D	0,24	0,50	0,41	0,43	0,47	0,46	0,30	0,29	0,25	0,37

#### 4.1. Sizing

To begin the sizing process, it is necessary to start with the payload already calculated previously:

- pv=payload volume≈1 m<sup>3</sup>
- pw=payload weight≈0,23 ton

To arrive at an initial estimate of the platform dimensions it is necessary to follow several equations and perform several iterations such that at the end the platform is balanced. Some of these equations are:



Volume of Displacement:

$$\nabla = \frac{\Delta}{\rho_w} \quad (7)$$

$\rho_w = \text{Density of Seawater} = 1,025 \text{ ton/m}^3$

Immersed Hull Dimensions:

$$L = M \nabla^{1/3} \quad (8)$$

$$T = \frac{\nabla^{1/3}}{[MK_B C_B]^{1/2}} \quad (9)$$

$$B = K_B T \quad (10)$$

When the entire sequence of iterations is completed, we have as a result an estimate of weight ( $W$ ) and required volume ( $V_{req}$ ) of the platform.

$$W = \sum_i w_i = \Delta \quad (11)$$

where:

$W$  – weight estimate [kg]

$w_i$  – is the  $i^{\text{th}}$  platform mass, [kg]

$\Delta$  - displaced mass, [kg]

$$V_{req} = \sum_i v_i = V \quad (12)$$

where:

$V_{req}$  – required volume [ $m^3$ ]

$v_i$  – is the  $i^{\text{th}}$  platform volume, [ $m^3$ ]

$V$  - volume, [ $m^3$ ]

If  $W = \Delta$  and  $V_{req} = V$ , then we have a balanced design. Otherwise, if  $W \neq \Delta$  or  $V_{req} > V$  the design is not balanced, and we should iterate using new values of  $W$  and  $V_{req}$  to replace the initial estimation [6].

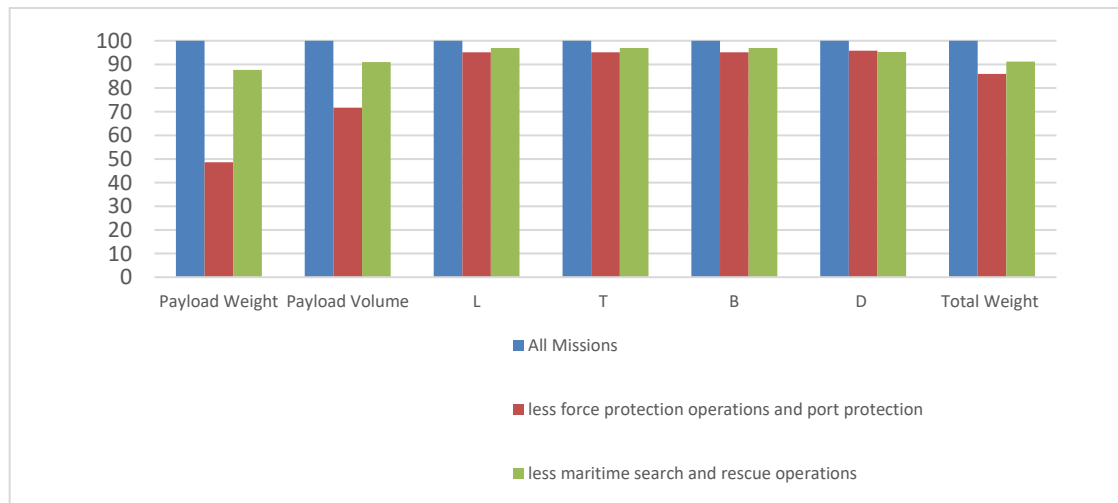
After several iterations performed, the desired result was reached, that is  $W = \Delta$  and  $V_{req} = V$ . The main initial dimensions of the USN-PoN are presented in table 4.

**Table 4** - Main dimensions of the platform.

L [m]	7,83
T [m]	0,55
B [m]	2,13
D [m]	1,36
W [ton]	3,42

In order to determine the impact of each mission on the dimensions of the platform, a study has been developed where a mission and its equipment (a configuration) is be removed, varying the payload (weight and volume).

Starting by removing the maritime search and rescue operations and repeating the entire sizing process. Then performing the same for the other configurations, we obtained some platform variations as presented in figure 3.



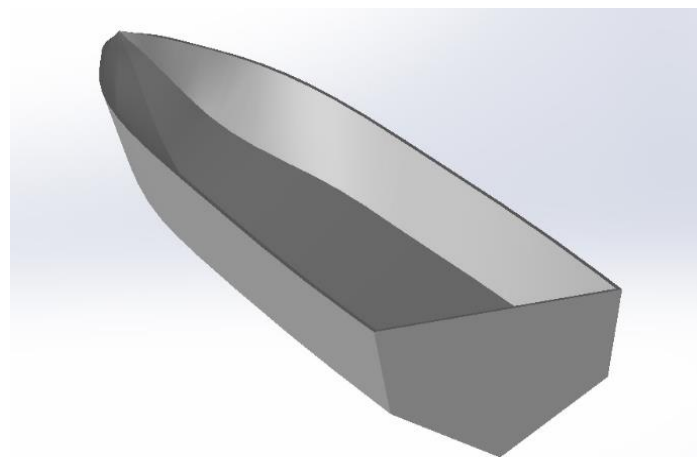
**Figure 3** - Effects of configuration changings on vehicle sizing

Removing environmental data collection operations and hydrographic surveys operations, the payload will not vary, therefore the dimensions of the platform will not vary. As removing maritime search and rescue operations and force protection operations and port protection do not cause significant changes in the dimensions of the platform, it was decided to maintain the initially calculated dimensions.

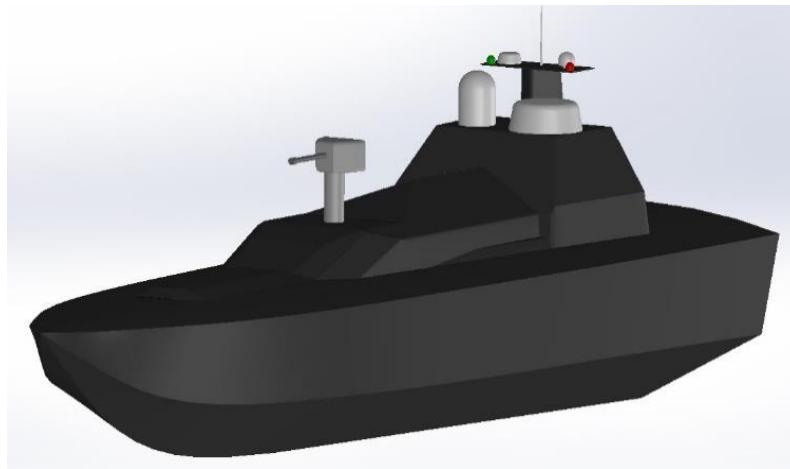
In order to have an initial estimate of the hull thickness a simple barge model was conceptualized where the applied load corresponds to its displacement, and it has been defined that the material to be used will be fiberglass-reinforced polymer as a low-cost and technologically accessible material.

#### 4.2. Geometric Modelling

Still in the *Project Definition* phase, we proceeded to model the platform using the *SolidWorks*® software.



**Figure 4** - 3D Model of USV-PoN hull

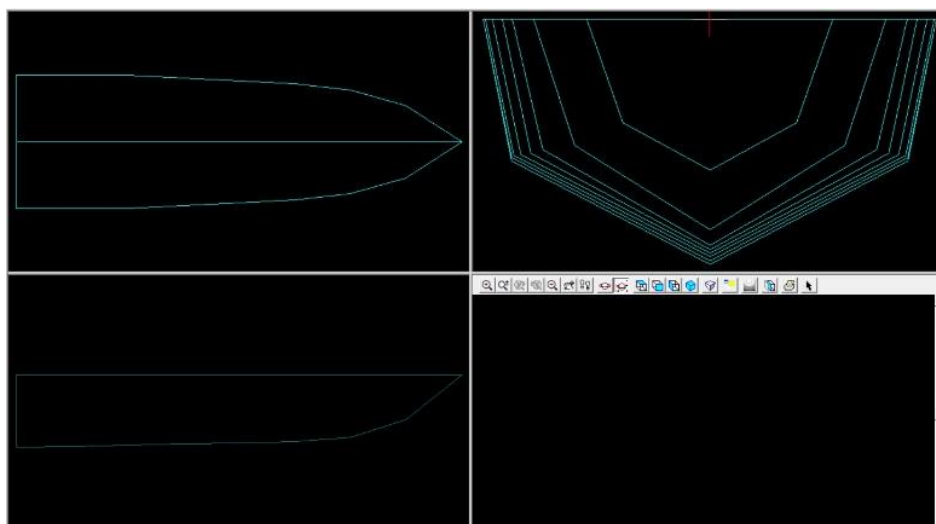


**Figure 5** . Initial 3D Model of USV-PoN.

## 5. Stability

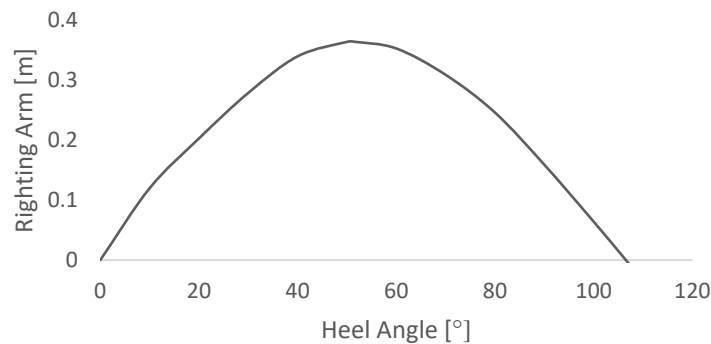
It will be important to study the stability of the USV-PoN in order to ensure that the platform can be used at sea as required and being self-righting. This study is inserted in the *Project Development* phase because it is a validation process.

To begin the study of stability, the platform was modelled in the *Modelmaker*<sup>®</sup> with the same coordinates used in *SolidWorks*<sup>®</sup>.



**Figure 6** - Modelling on Modelmaker<sup>®</sup>

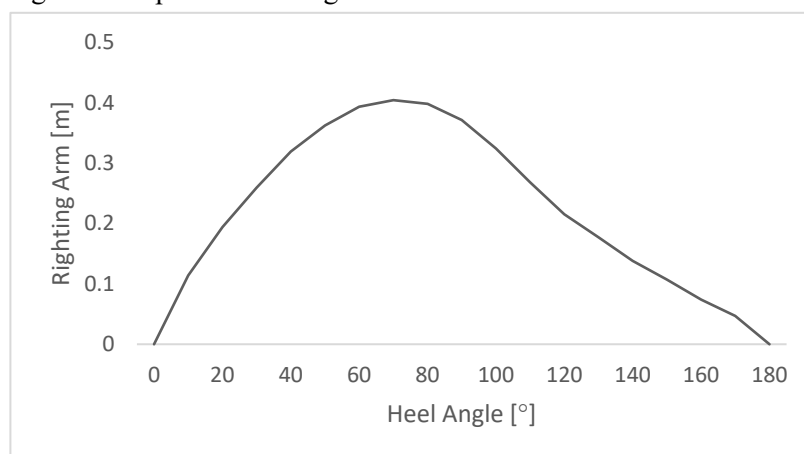
After *Modelmaker*<sup>®</sup> modelling, it is possible to export the platform to *AutoHydro*<sup>®</sup> to perform stability calculations. The calculated righting arm is represented in figure 7.



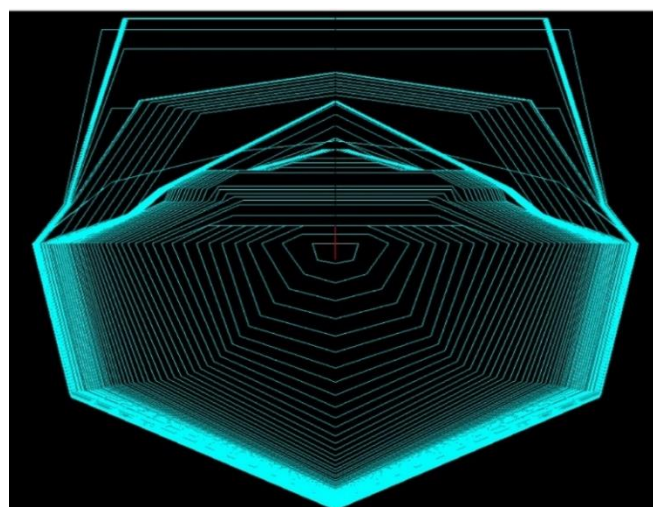
**Figure 7** – Initial righting arm curve of the USV-PoN.

As from the study of the resulting curve in figure 7 it can be seen that the USV-PoN doesn't have self-righting characteristics, a further detailed stability study had to be developed to ensure the that characteristic.

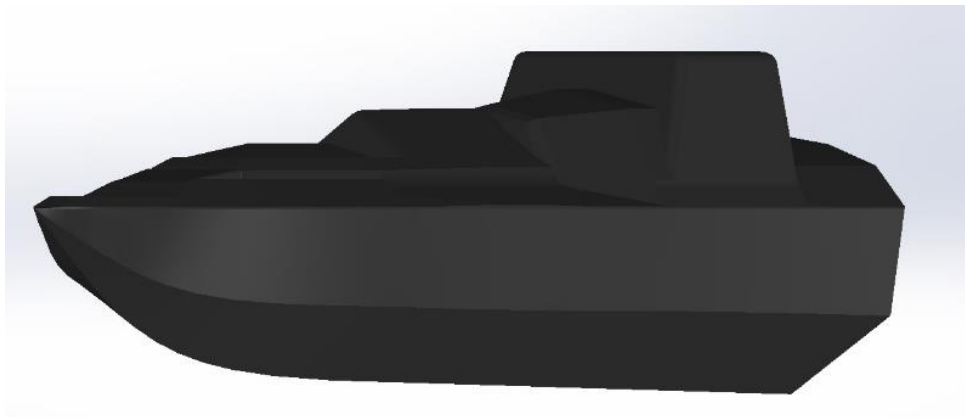
After several iterations altering the shape platform, a model of the self-righting vehicle was reached. The curve of righting arm is represented in figure 8.



**Figure 8** – Righting arm curve of the self-righting USV-PoN



**Figure 9** - Modelling on Modelmaker® of self-righting USV-PoN



**Figure 10** - 3D Model of self-righting USV-PoN.

## 6. Conclusions

In this paper the conceptual design of an USV to be applied in the Portuguese Navy was developed, following a framework of acquisition and construction of military means. Inserted in this framework, several analytical-empirical methods were used in order to obtain the desired objectives.

With a wide variety of missions to perform by the platform, which leads to a high number of equipment and sensors, it was a challenge to make the design comply with the sizing and weight constraints.

The objective of designing a self-righting platform was achieved, however, much further work will be needed. It will be necessary to perform the following studies:

- resistance and propulsion, with associated maximum speed levels, propulsion selection, and vehicle endurance,
- cost estimates,
- weapon and sensors arrangement and energy demands,
- seakeeping,
- command and control and associated levels of artificial intelligence.

After all these studies it will be necessary make a new iteration with the inputs of the end user .

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